Integrated Development Platform for Customer and Aggregator Energy Management Systems (Grant Agreement No 101172675)

D2.1 Initial Requirements and IDOP Architecture

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Index:

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1 Executive summary

This document describes the initial requirements and architecture for the Integrated Development and Operations Platform (IDOP) implemented in WP2. The requirement engineering and architecture design is implemented in two main phases, each of which consists of several agile R&D iterations. This document describes the work done in the first phase, comprising the work done in WP2 in the tasks of T2.1 - Use cases and requirements, T2.2 - Architecture of the INDEPENDENT Platform, and T2.3 - Security and GDPR-compliant privacy design. The common standards and best practices are followed in requirements engineering and architecture design to ensure interoperability, trust and privacy.

IDOP consists of three packages: Customer Energy Management System (CEMS), Aggregator Energy Management System (AEMS), and DevSecOps & Investment Support Package. The work starts by describing business use cases of four project pilots: German, Finnish, Swedish and Slovenian. The requirements engineering for the IDOP and associated incentives and business models (T2.1) is an iterative process, analyzing the use cases from the business viewpoint and ending up with an initial set of general requirements associated to CEMS, AEMS, and DevSecOps & Investment Support Package. These requirements are used as a starting point for designing a common architecture for the IDOP. The architecture design is described with the help of an example system utilizing the IDOP. The architecture design (T2.2) follows the common standards for architecture documentation and describes the architecture of an IDOP based system from the context, functional, information and deployment viewpoints. The context, functional, deployment viewpoints are represented with corresponding diagrams and the architectural elements of the diagrams are described in more detail and associated with the data the elements manage. The information view is presented by describing the data units, types, relevant resources, systems, and information/ knowledge identified in the context and functional views. Finally, the deployment view represents how the components are implemented and deployed into different computing platforms. The use cases described in T2.1 are also explored from multiple trust, security, and privacy (TS&P) dimensions and the TS&P related features are designed to ensure a common, open, and privacy-aware trust management and security architecture (T2.3). At the end, three different kind of system use cases are described that enable to design the interaction between functional components: demand-side flexibility aggregation for energy wholesale markets, demand-side flexibility aggregation for TSO reserve markets, and local flexibility management.

Later, in phase two, the requirement engineering and architecture design will continue by identifying the requirements in more detail (from functional and non-functional viewpoints) and updating the architectural descriptions based on the requirements and feedback from the first phase pilots.

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2 Introduction

2.1 Purpose, context and scope

Requirements engineering and architecture design of the IDOP is implemented in two phases. This document describes the requirements and the initial system architecture of the IDOP implemented in the first phase. The final requirements and architecture are described later in the INDEPENDENT project and will be described in D2.3.

This document gathers the work implemented in the following tasks:

- T2.1 - Use cases and requirements
- T2.2 - Architecture of the INDEPENDENT Platform
- T2.3 - Security and GDPR-compliant privacy design

T2.1 documents the business use cases from each pilot and derives requirements for the IDOP and associated business models. The task uses as a starting point the use cases and requirements documented in existing standards and technical reports (i.e., IEC/TR 62746-2:2015 and EN 50491-12-1), and the related projects (RESONANCE and iFLEX). The use cases are documented by providing an objective, scope and description of each use case. In addition, the use cases are analyzed for possible conflicts and missing functions. The requirements engineering is an iterative process that follows the established Smart Grids UC methodology. The requirements are defined first from the business perspective and are described with the requirements description table. Later, in the phase two of the requirements engineering and architecture design, the requirements are identified also from the technical viewpoint and are described in more detailed in D2.3.

T2.2 describes the common architecture for the IDOP based on the use cases and requirements. The architecture design is an iterative approach, and the work follows the ISO/IEC/IEEE 42010:2011 standard, documenting the architecture with the stakeholders, views, and perspectives. At first, the context view is defined that specifies the relevant stakeholders and external systems that interact with the CEMS and AEMS developed with the IDOP. Next, the context view is divided into logical subcomponents in a functional view, documenting the modules of CEMS and AEMS. After the functional view, the identified data models are specified and documented in the information view. Finally, the deployment view describes how the CEMS and AEMS are packaged and deployed into different computing platforms (i.e., cloud, edge computing platforms, mobile phones). The architecture is designed further with three system use cases that enable to identify the interactions and responsibilities for the functional components. In the first phase, the abovementioned four viewpoints are described. In the second phase, the descriptions will be updated with feedback from the first phase pilots (will be described in D2.3).

T2.3 designs the trust, security and privacy (TS&P) related features of the common IDOP and its functional components. The use cases described in T2.1 are explored from multiple TS&P dimensions, from trust and identity management, secure communication between components and entities, secure and privacy aware data spaces provisioning to implementation and operations oriented DevSecOps. The design process takes into account the requirements from standards, regulations and national regulation, and follows the architectural views as described in T2.2. The design concludes outlining the trust, security, and privacy requirements for the INDEPENDENT Platform.

2.2 Content and structure

This document is structured as described in the following:

- Section 3 documents the work done in T2.1, describing the use cases and their objectives on a high level, and then providing an initial set of common requirements for the IDOP derived from the business perspective.
- Section 4 documents the common architecture for the IDOP defined in T2.2, driven by use cases and requirements described in T2.1. The architecture is described with the help of views (context, functional, information and deployment), and with security and privacy perspective (defined in T2.3) that designs the trust, security and privacy related features of the common IDOP and its functional components.

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- Section 5 describes three system use cases that present the interaction between functional components in given scenarios: demand-side flexibility aggregation for energy wholesale markets, demand-side flexibility aggregation for TSO reserve markets, and local flexibility management.
- Finally, section 6 concludes the work.

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3 Business use cases and requirements

This section first describes the business use cases of the German, Finnish, Swedish and Slovenian pilots and then gathers the common requirements for the IDOP derived from the pilots.

3.1 Business use cases for the German pilot

Phase 1 of the pilot will encompass an industrial site and ten residential pilot sites. These pilots aim to demonstrate the scalability of the DE-BUC1, DE-BUC2, and DE-BUC3 use cases. It is anticipated that a tradeable amount of flexibility will soon be identified for the industrial site. The residential pilot installations focus on local optimization and compliance with the German §14a EnWG for grid intervention.

Table 1: Business use case 1 of the German pilot.

Name of the use case	**DE-BUC1 Flexibility Aggregation and Trading**
Objective and scope	The objective of this use case is to enable both the Customer Energy Manager (CEM) and Aggregators to aggregate and facilitate the trading of flexibility potentials. This requires that Resource Managers (RMs) have the capability to shift loads within a defined flexibility corridor. Additionally, effective communication of flexibility potential between the RM and the CEM must be established. On the other side, the Aggregator must develop and provide a pricing model tailored to flexibilities, ensuring seamless integration into the market.
Description	This use case enables the aggregator to gather and activate flexibility potentials. Also providing and profiting from offering flexibility potential for CEM user is included. The flexibility potential is determined by the CEM's by analysing the energy potential of the connected RM's using various calculation methods to identify the available flexibility. Additionally, it is assessed which utilization mode is feasible for utilizing the potential. The utilization mode provides critical information on whether the identified potential can be accessed at any level, only above a minimum threshold, or only in its entirety. The information regarding availability, dispatchable capacity, and dispatch mode is provided to the aggregator. Based on the collected data from all flexibility providers, the aggregator can select suitable offers and request the flexibility potential by sending activation messages. Upon receiving an activation message, the CEMS controls the respective assets and activates them while considering the requested capacity. This ensures that the flexibility is efficiently and appropriately delivered.

Awaiting approval

Table 2: Business use case 2 of the German pilot.

Name of the use case	**DE-BUC2 Cost orientated energy system optimization**
Objective and scope	The objective of this use case is to enable the CEM to optimize energy systems in a cost-oriented manner. Achieving this requires the implementation of an energy system model and the collection of real-time data from all assets. The outcome is the generation of optimized schedules for all relevant assets, enabling cost-effective operation of the energy system. To support this use case, seamless data exchange between all RMs and the CEM must be established, allowing the sharing of asset information and the optimized schedules for each RM. Furthermore, the integration of external data such as weather conditions and price forecasts is essential for effective optimization.

Description	For this purpose, cost-related data is additionally required for each RM. This includes operating costs (energy-based or time-based) as well as start costs. Furthermore, general energy system data is necessary, such as energy prices, forecasts of energy demand, and expected energy generation. Based on this data, the energy system is modelled within an optimization framework to determine the most cost-efficient operating strategy. The outcomes of this process are schedule recommendations for the individual regulatory modules. However, if relevant parameters deviate from the planned operation and exceed operational limits, the regulatory module may deviate from the predefined schedule. The described optimization cycle is repeated at regular time intervals. During each iteration, the current data of the RMs is collected, deviations from the forecasts are analysed, and the optimization is re-executed based on newly generated forecasts.

Table 3: Business use case 3 of the German pilot

Name of the use case	**DE-BUC3 Emergency Management**
Objective and scope	The objective of this use case is to empower TSOs or DSOs to leverage CEMs for emergency management within the grid. This involves enabling CEMs to provide detailed information about their ability to support grid interventions by adjusting their schedules as required. Specific regulations need to be specified by the system operator.
Description	This use case focuses on enabling TSO and DSOs to integrate CEMs into grid emergency management. TSOs or DSOs continuously provide the current grid status using a classification system that indicates whether no intervention is required, or specific regulation is needed. Based on this information, CEMs can respond by dynamically adjusting their RMs, scaling down consumption as necessary to reduce grid stress. This coordinated process ensures efficient grid stabilization during critical conditions. Reliable, real-time communication between grid operators and CEMs is essential to execute these adjustments effectively. The opposite behaviour (increasing the load) will be evaluated.

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3.2 Business use cases for the Finnish pilot

In the phase 1, the Finnish pilot includes a supermarket and an apartment building. The FI-BUC1, described in Table 4, is targeted for the supermarket chain that acquires their energy directly from the Nord Pool day-ahead market. The FI-BUC2, presented in Table 5, is suitable for more classical consumers and will be demonstrated in the apartment building.

Table 4: Business use case 1 of the Finnish pilot.

Name of the use case	**FI-BUC1: Explicit demand response in the wholesale energy markets**
Objective and scope	This use case focuses on explicit demand response in the wholesale energy markets. The BUC targets large consumers that acquire their energy directly from the markets. The goal of the BUC is to enable large consumer to benefit from varying energy prices by utilizing demand flexibility directly in the wholesale energy markets.
Description	This business use case focuses on large consumers that acquire their energy directly from the day-ahead (and intraday) markets. In this case the retailer and the building owner (consumer) are typically part of the same organization as is

	the case with the supermarkets in the Finnish pilot.[1] The retailer acts as an Aggregator whose objective is to use the flexibility of the consumers to acquire the energy as cost-efficiently as possible from the day-ahead (and intraday) market. By targeting the day-ahead and intraday markets, and managing the aggregated balance, the Retailer can minimize costs by purchasing energy during the cheapest hours and shifting consumption accordingly. To this end, the Aggregator is equipped with an Aggregator Energy Management System (AEMS) and each building is operated by a Customer Energy Management System (CEMS). The AEMS provides CEMS with two-day price forecast for the day-ahead market. Each CEMS optimizes their energy consumption to minimize their cost with respect to the price forecast (and possible local incentives). Additionally, the CEMS provide AEMS with baseline and flexibility forecast (including costs for flexibility activation). The AEMS leverages flexibility forecasts, building consumption baselines, and electricity price forecasts to optimize energy procurement and usage in the energy markets. Both the Retailer and the building owner benefit from reduced energy costs. A contract between the large consumer (i.e., the owner of the buildings) and the retailer specifies how the cost savings are shared between the parties.

Table 5: Business use case 2 of the Finnish pilot.

Name of the use case	**FI-BUC2: Implicit demand response**
Objective and scope	The primary objective of this use case is to reduce energy costs by leveraging implicit DR. The CEMS receives real-time market spot price signals and uses this information to control and optimize the building's energy consumption. By dynamically adjusting energy use in response to price fluctuations, the system ensures cost efficiency while maintaining operational effectiveness.
Description	Implicit demand response enables consumers to adjust their energy consumption based on real-time or dynamic pricing, allowing for cost savings. In this BUC, a residential building with self-contained flats has a spot-price electricity contract, motivating the Building Owner to optimize energy use. The building's hybrid heating system, comprising an exhaust air heat pump and district heating (DH), is the primary focus for optimization. DH includes seasonal pricing and peak load charges, which must be considered. A Customer Energy Management System is installed to automate energy management. It interacts with the building's Building Automation System (BAS) to 1) shift energy consumption in response to hourly spot prices and 2) determine whether to use the heat pump or DH based on real-time cost efficiency. To this end, the CEMS uses inputs like the building's thermal inertia, heating system dynamics, weather forecasts, and occupancy patterns to optimize operations. These factors, along with predetermined boundaries set by the Facility Manager (e.g., minimum thermal temperature for resident comfort), guide the system's decisions. The Facility Manager ensures that the system operates within agreed comfort levels defined by a contract between the Building Owner and residents. While the CEMS manages energy use automatically, the Facility Manager can override settings if necessary, ensuring both cost savings and resident comfort are maintained.

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[1] It is also possible that the large consumer subcontracts the retailer services from external company in which case there needs to be a contract between these actors.

3.3 Business use cases for the Swedish pilot

The Swedish Pilot involves residential homes equipped with heat pumps, EV Chargers, PV electricity generation, battery storage and possibly other controllable energy resources. Resources may have local smart control systems and may be connected by equipment manufacturers' connectivity solutions or be connected via an Aggregator's deployed control equipment hosting CEMS services.

Within this context, the pilot will address three business use cases that have as a common objective to lower costs or even create revenues for the homeowners without sacrifices in experienced climate system comfort.

Table 6: Business use case 1 of the Swedish pilot.

Name of the use case	**SE-BUC01: Ancillary Services using aggregated heat pumps in residential buildings**
Objective and scope	Heat pumps are commonly used in Swedish homes, potentially allowing tens of thousands of units to participate in TSO service markets if response times and volumes meet requirements. In this use case, an Aggregator will connect, aggregate and bid aggregated heat pump resources for ancillary services in Sweden, evaluating their technical and financial viability as part of the pilot.
Description	The Aggregator (market integrator) will connect heat pump resources via the manufacturer's cloud connectivity solution that act as a sub-aggregator. The aggregated heat pumps are thus seen as a virtual CEMS (CEM with large amount of RMs. As each residential heat pump represents a quite small amount of available flex power, typically in the range of 1-2 kW, multiple layers of aggregation will be required to cater for required bid volumes, including safety margins. A simulation on mFRR ancillary services in Sweden using residential heat pumps suggests a yearly revenue of about EUR 120 per home and without hardware investment needed on site. Other ancillary services are expected to yield revenues in the same range and the potential revenue per heat pump is thus expected to be relatively small. A profitable solution will require very low operational costs per unit. A challenge of this use case is to ensure that operations do not cause any discomfort in terms of temperature or hot water availability for the residents. Additionally, homeowners have the option to override the central control with local control and behaviour, allowing them to maintain their comfort preferences and manage their energy resources according to their needs. This might lead to situations where planned ancillary services cannot be delivered as bid. This needs to be taken into consideration at both CEMS and AEMS levels.

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Table 7: Business use case 2 of the Swedish pilot.

Name of the use case	**SE-BUC02: Ancillary Service Stacking combining heat pumps, PV and battery resources**
Objective and scope	The objective of this use case is to evaluate how a combination of energy resources can support ancillary service stacking with increased revenue generation compared to a single service solution as in SE-BUC01. The primary scope is to include PV electricity generation, batteries and heat pumps, but additional resources may be included.
Description	Ancillary Service Stacking refers to the practice of using energy resources, like batteries, to provide multiple grid services simultaneously. These services can include capacity services, energy shifting, and fast-response ancillary services.

	In this use case, we aim to evaluate how a combination of several different controllable resources from residential buildings can be used in a service stacking context. Batteries contribute with the possibility of fast response and high-power levels per device and heat pumps can contribute with low cost for flexibility and longer endurance over time to over or under consume energy.

Table 8: Business use case 3 of the Swedish pilot.

Name of the use case	**SE-BUC03: Optimization of power tariffs costs combining heat pumps, PV and battery resources**
Objective and scope	The main objective of this use case is to minimize power tariff costs in a residential setting with a combination of several smart energy resources where each one has a significant impact on the power used. As a sub objective, the parallel maximum participation in ancillary services should be considered for increased revenues. The scope includes residential homes with heat pump, battery and EV charger resources connected to 5-10 different grid companies.
Description	Homeowners face several challenges related to power tariffs, especially as energy consumption increases due to large electricity consumers like heating systems, hot water generation, and electric vehicle (EV) charging. Key issues include peak demand charges and penalty fees. Many electricity providers impose penalties if a household exceeds or increases its contracted power limit. High-demand appliances—such as EV chargers, heat pumps, and water heaters—can create peak loads, especially when used simultaneously. The Swedish Energy Markets Inspectorate (Ei) has decided that starting in 2027, a capacity charge based on network constraints, must be included in the network tariff for all electricity customers. As of now (January 2025), around 50 of Sweden's approximately 170 electricity grid companies have already implemented a capacity charge. Grid companies are free, within limits, to use different tariff models leading to a large variation in terms and fees. While aiming for minimized tariff costs, it will still be possible to take part in certain types of ancillary services to some extent, especially considering use case SE-BUC02, wherein clever combinations of different devices could mitigate risk of costly power tariff for the end consumer. This option will be investigated in this use case to further increase profitability of smart energy control systems.

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3.4 Business use cases for the Slovenian pilot

The Slovenian pilot involves residential homes, apartment buildings and industrial facilities. In the INDEPENDENT project three pilot use cases will be addressed: the Automated implicit demand response involving all three pilot groups, the Local flexibility market and TSO-DSO cooperation involving residential homes and the Flexibility package and BSP SouthPool cooperation engaging a broader range of households in Celje region. The three use cases have different objectives: the first one aims at lowering the costs and increase self-consumption, the second one aims at utilizing available residential houses flexibility at network level and the third one validates utilization of a flexibility package offered by the retailer.

Table 9: Business use case 1 of the Slovenian pilot

Name of the use case	**SI-BUC01: Automated implicit demand response**
Objective and scope	The scope of the use case is related to (1) households and their distinct

	resources, to (2) apartment buildings with diverse set of energy sources for heating and to (3) industrial facilities. The energy users' resources are controlled according to the implicit external or internal signals, like day ahead prices, network tariffs, CO2 emissions mix information or local PV production. The objective of the use case is to automate the optimization of individual local load and generation within the energy users, aiming to lower costs, increase self-consumption, reduce CO2 emissions, or improve resource usage efficiency.
Description	Automated implicit demand response uses information from external sources, such as day ahead prices, network tariffs or CO2 emissions and internal sources, like PV production, to optimize the usage of energy users' resources according to the end user preferences and environment conditions, like weather. This optimization aims to lower energy costs, increase self-consumption, reduce CO2 emissions, or improve resource usage efficiency. In case of individual households, the households' resources like heat pumps, EVs, PVs, white goods and batteries are modelled as Resource Managers (RM) and controlled by the Customer Energy Manager (CEM) according to specific implicit signal or combination of such signals. According to the signal, weather conditions and individual RM load and generation models, the CEM prepares optimized schedule for the next time horizon. The procedure is repeated at predefined time slots. The apartment building uses electricity and gas as energy sources for heating. The two heating sources together with a building will be modelled as RMs. According to the weather conditions, overall price of energy, state of the heating system and its past states combined with the building, the CEM decides which energy source to use and which set-points to set and follow in the next time horizon. The diary farm is an industrial facility that includes a cold storage, various industrial processing equipment, a PV and a battery. The primary signals for the implicit control are network tariffs, PV production and entire load of the facility. The aim of the optimization is to limit the peak load of the facility. The CEM prepares the cold storage and battery optimal schedule for the next horizon according to the implicit signals and repeats the procedure of the schedule preparation at predefined time slots.

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Table 10: Business use case 2 of the Slovenian pilot

Name of the use case	**SI-BUC02: Local flexibility market and TSO – DSO cooperation**
Objective and scope	The use case connects consumers, prosumers, aggregators, DSOs and the TSO with the local flexibility market. The consumers, prosumers and aggregators act as a flexibility providers and the DSOs and the TSO as flexibility seekers in the market. The local flexibility market enables communication of flexibility needs and flexibility offers between market participants and settlement of the deals agreed on the market. The TSO can utilize flexibility offered in the local flexibility market if the DSOs network allows it based on the current network conditions.
Description	In a local flexibility market, System Operators (SO, DSO or TSO) seek flexibility by publishing requests for additional energy resources. Flexibility providers, such as aggregators, respond with offers based on their capabilities. The SO evaluates the offers and selects one based on flexibility request and predefined criteria. Upon acceptance, the provider delivers the required flexibility while adhering to specified conditions, such as amount, duration and locality. After the provision is complete, the market verifies the delivery against the request and settles the financial aspects of the transaction. In access to the local flexibility market, the DSOs have priority over TSO. Offers not utilized by the DSOs can be accessed by the TSO if allowed by conditions in the DSO network. The market employs a traffic light signal (TLS) system to signal

	the status of the low-voltage distribution network at any time. In the case of a green light, the distribution network will allow an increase in either consumption or production of electricity. An orange signal will mean that action is required in terms of adjusting consumption or production on the distribution network side. A red signal will mean that the network does not allow any increase and is practically operating at its maximum capacity, so no flexibility in the DSO local network can be utilized by the TSO.

Table 11: Business use case 3 of the Slovenian pilot

Name of the use case	**SI-BUC3: Flexibility package and BSP SouthPool cooperation**
Objective and scope	The objective of the use case is to describe how prosumers can offer their flexibility through a flexibility package prepared by the retailer. The package assumes a battery will be installed at the prosumer that can be controlled by the retailer. The flexibility harvested can be used to optimize retailer market participation and to offer it on the BSP SouthPool for diverse set of services.
Description	A retailer offers a flexibility package to its prosumer clients. The flexibility package includes a battery the retailer can control in exchange for a fixed price of energy. The retailer control of the battery and related production and consumption at the household aims at flexibility harvesting of the battery (and household) flexibility potential. The harvested flexibility will be used to optimize retailer market participation and mitigate the market price volatility. The flexibility can also be offered on the BSP SouthPool market. The business use case is based on the use of implicit Demand Response (DR) in connection with day-ahead electricity prices, where the retailer manages the control of the prosumer's solar power plant, battery storage system and other appliances. In exchange for control over the devices, the user receives an extended billing period of up to one year. This allows electricity to be stored through day during periods of low prices and used during periods of high prices, optimizing costs, improving renewable energy efficiency, increasing self-sufficiency, and providing a competitive advantage for the retailer and electricity price reduction for prosumers. Furthermore, by leveraging aggregated local flexibility, the retailer will be able to mitigate intraday fluctuations in electricity supply and demand. In cooperation with the SI-BUC02 it will be evaluated how to offer the flexibility package on the local flexibility market and what are the benefits for the retailer, DSOs and TSO.

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3.5 Common requirements for the Integrated Development and Operations Platform

The common requirements for the Integrated Developments and Operations Platform, derived from the Business Use Cases, are presented in Table 12, Table 13, and Table 14.

Table 12: Requirements for Customer Energy Management Systems Package.

ID	Requirement	Description
CR1	Integration with legacy automation and metering infrastructure.	CEMS need to be able to collect measurement data and send control signals to building and home automation systems, smart meters, and other metering infrastructure in the consumer premises.
CR2	Optimize energy consumptions	CEMS need to be able to optimize energy consumption taking into account user preferences and limits, dynamic energy and network prices, local production from PVs, and energy efficiency of the building/site. The CEMS will control resources (flexible assets) according to the optimized schedule.
CR3	Baseline power forecast	CEMS need to be able to provide the AEMS with baseline power forecast (i.e., optimized load profile).

CR4	Flexibility forecast/estimate	CEMS need to be able to provide AEMS with forecast/estimate of the available flexibility and related costs (i.e., what is the compensation required if CEMS deviate from the locally optimal profile).
CR5	React to explicit flexibility activations	CEMS need to be able to activate the offered flexibility when requested by the AEMS.
CR6	User interaction	CEMS need to be able to collect user preferences, limits, and goals. CEMS need to be able to provide users with visualisations on energy consumption, system state, and results of DSFM actions (e.g. costs savings and CO2 emission reductions).

Table 13: Requirements for Aggregator Energy Management Systems.

ID	Requirement	Description
AR1	Integration with energy and flexibility markets	AEMS need to be integrated with relevant energy (day-ahead and intraday) and flexibility markets (e.g. TSO reserve and DSO local flexibility markets) to perform automated bidding.
AR2	Market price forecasting	The AEMS need to provide CEMS with day-ahead price forecast. Additionally, price forecasts for the intraday and flexibility markets are required in the multi-market bidding.
AR3	Aggregated flexibility management	AEMS need to be able to aggregate the baseline and flexibility
AR4	Flexibility bidding	The AEMS need to be able to optimize the flexibility when bidding in energy and flexibility markets.
AR5	User interaction	The AEMS need to provide aggregators with user interface to manage their goals and preferences, and view performance reports and system status information.
AR6	Support for sub-aggregation	The AEMS Package needs to support the decoupling of technical aggregation and market integration/bidding functionalities into independent AEMS. This is required because some actor might be only interested in aggregation of demand flexibility while other focus solely on market integration.

Table 14: Requirements for DevSecOps and Investment planning.

ID	Requirement	Description
DR1	Secure deployment and operations	The IDOP needs to provide means for secure deployment and operations of CEMS and AEMS.
DR2	Secure and privacy-aware data sharing	The IDOP needs to provide data spaces enabling secure and privacy-aware sharing of data from buildings and industrial site among the stakeholders developing DSFM solutions.
DR3	Support for investment planning	The IDOP needs to provide tools that enable aggregators and customers to analyse the potential benefits and return on investments.

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4 Common system architecture

This section first describes the main packages and modules of the IDOP, after which an IDOP based example system is presented to illustrate how the modules of the IDOP can be used.

4.1 Integrated Development and Operations Platform

The architecture of the Integrated Development and Operations Platform consists of three main packages as illustrated in Figure 1.

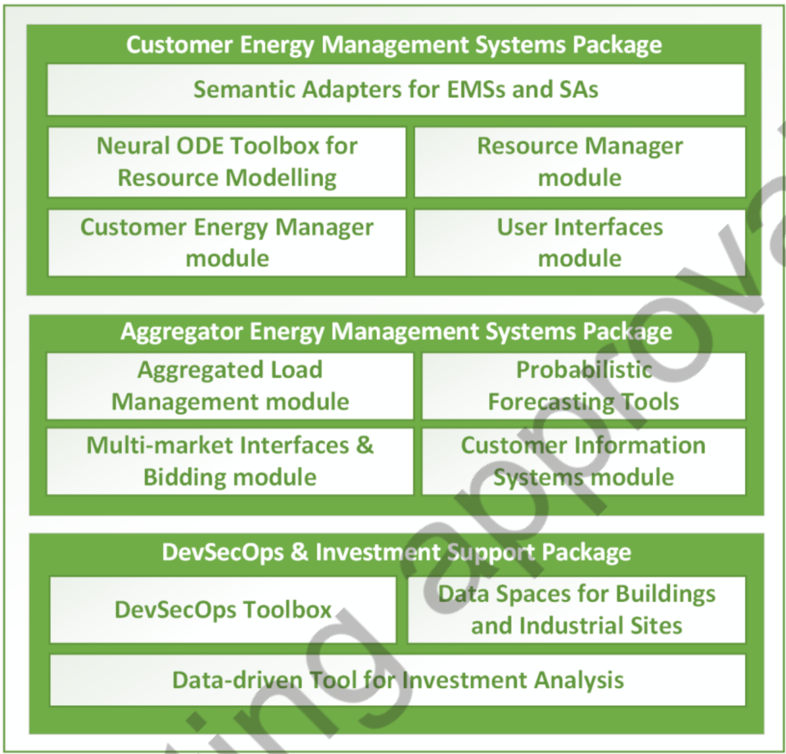

Figure 1: Overview of the Integrated Development and Operations Platform.

The CEMS Package includes five modules aligned with the CEMS architecture introduced in the EN 50491-12-1 standard (CENELEC, 2018). Separate modules are provided for the Resource Manager (RM) and Customer Energy Manager (CEM). These modules deliver the respective S2 interface libraries, optimization models, and control algorithms. These modules support three categories of optimization targets: local optimization, implicit control, and explicit control. Furthermore, they implement five control models as specified in the EN 50491-12-2 standard (CEN-CENELEC, 2022). Additionally, the CEM module implements the Resource Role of the DSFM interface defined in the new IEC 62746-4 standard (IEC, 2024). The Semantic Adapters for EMSs and SAs module will provide interfaces for a wide variety of resources, including heat pumps, building automation systems, photovoltaic systems, smart meters, and other metering infrastructure. The Neural ODE Toolbox enables automated resource modelling with Neural ODEs, supporting optimal Model Predictive Control (MPC) of resources and accurate baseline and flexibility forecasting. The User Interface module allows different user types to define preferences and goals, monitor CEMS performance, and provide feedback.

The AEMS Package consists of four modules. The Aggregated Load Management module offers standard-compliant interfaces for aggregating and managing flexibility from CEMS and implements the Operator Role of the CEMS interface (to be defined in the IEC 62746-4 standard (IEC, 2024)). The Probabilistic Forecasting Tools module provides methods for probabilistic forecasting of prices, aggregated demand, and flexibility required in stochastic multi-market bidding. Aggregated demand and flexibility forecasting provide hierarchical forecasting to correct aggregated forecasts by learning from the residuals of the CEMS-level forecast generated with Neural ODEs. The Multi-Market Interfaces and Bidding module includes market interfaces and optimization models for multimarket operations to break market silos and maximize the value of flexibility. Interfaces for eight different energy wholesale, TSO, and DSO flexibility markets will be developed during the project. The Customer Information Systems module ensures secure and GDPR-compliant data management services for customer data, supporting customer pooling based on their retailer or network topology location, as required in explicit demand response (DR) for wholesale markets and flexibility services for DSO-TSO cooperation.

The DevSecOps & Investment Support Package consists of three modules. The DevSecOps Toolbox module facilitates automated deployment, security, and operations of CEMS and AEMS. Trust, security, and privacy (TS&P) are integrated as shared responsibilities throughout the system life cycle. Each module instance is packaged as a microservice (container) for flexible deployment in cloud and edge environments. For instance, deploying CEMS on an edge computing platform ensures operational resilience against network disruptions. The Data Spaces for Building and Industrial Sites module provides Gaia-X and European Data Exchange Reference Architecture (DERA) 3.0 compatible data spaces, enabling secure and governed data sharing across stakeholders. This supports resource modelling and data-driven estimation of benefits from IDOP. The Data-driven Tool for Investment Analysis simulates benefits and payback times using models and parameters consistent with operational control and forecasting, enhancing the accuracy of return-on-investment forecasts.

4.2 IDOP based system architecture

To better understand the IDOP and its usage, it is useful to document an architecture of an example IDOP based system. In this section, an example system utilizing the IDOP is documented. The system architecture will represent an operational DSFM system and therefore mainly focus on the CEMS and AEMS packages. The architecture documentation follows the ISO/IEC/IEEE 42010:2011 standard(*ISO/IEC/IEEE 42010:2011 - Systems and software engineering - Architecture description*, 2011), which includes engaging stakeholders and utilizing a views and perspectives methodology. In the next sub-sections, the IDOP based system is presented with four architectural views, and security and privacy perspective.

4.2.1 Context View

Figure 2 illustrates an example of the IDOP based system: an AEMS aggregates several CEMS (and possible other AEMS as well), manages their flexibility, and provides the combined flexibility to the energy and flexibility markets. The IDOP elements (i.e., AEMS and CEMS) are represented with green, site-specific external systems with blue and energy and flexibility markets with orange.

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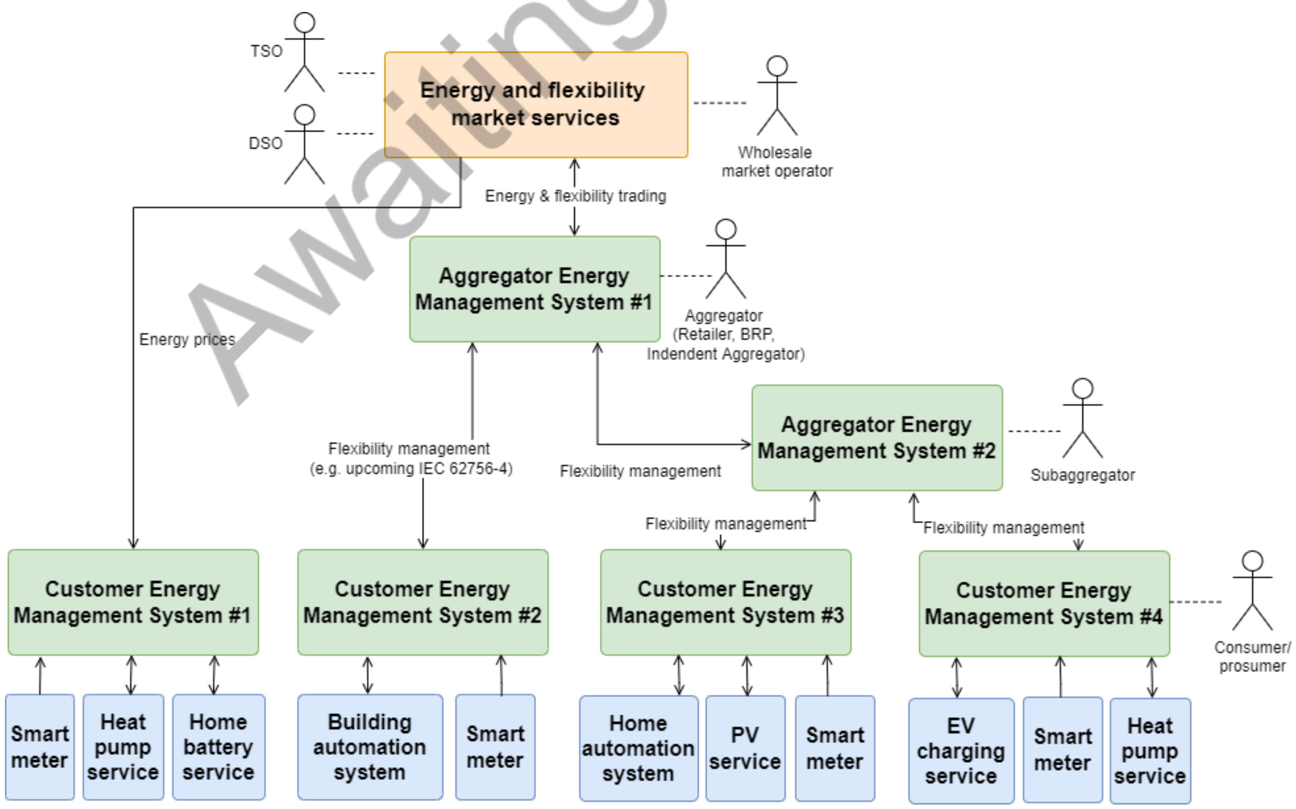

Figure 2: IDOP based system.

Figure 3 illustrates a context view of an IDOP based system: the main components; an AEMS and a CEMS, are presented as black-boxes and their interaction with each other, other stakeholders and external systems are described. The elements of the context view are described in more detailed in Table 15.

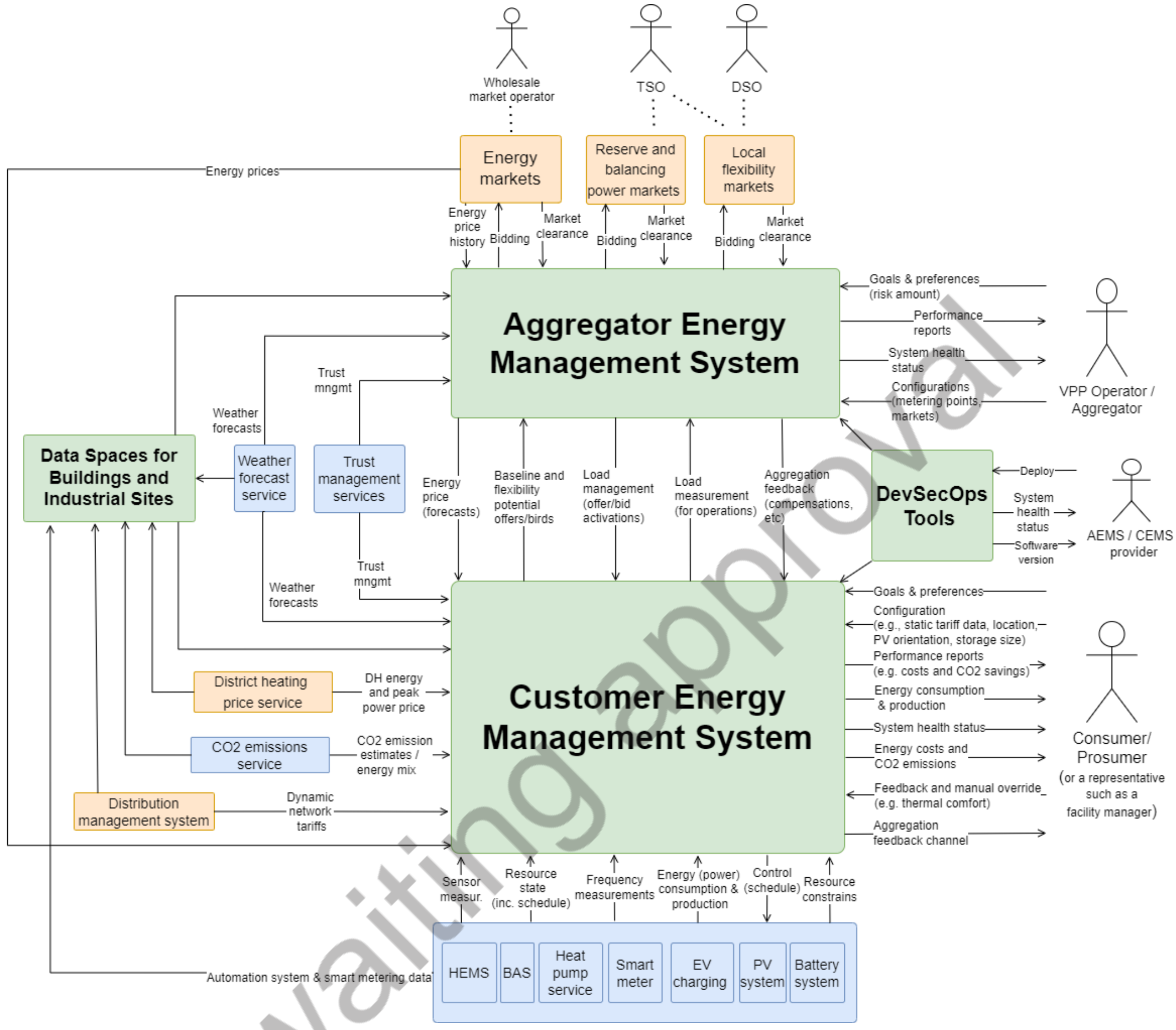

Figure 3: Context view of an IDOP based system.

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Table 15: Description of elements of the context view.

Element	Description	Managed data
Aggregator Energy Management System	A solution for aggregating and managing flexible resources in multi-market setting. Based on the AEMS Package of the IDOP.	Bidding Load management signal price forecast Performance reports System health status
Local flexibility markets	Markets that provides data about current bidding and market clearance to AEMS.	Bidding Market clearance
Reserve and balancing power markets	Markets that provides data about current bidding and market clearance to AEMS.	Bidding Market clearance
Energy markets	Markets that provides data about current bidding and dynamic price history data to AEMS.	Bidding Market clearance Energy price (and history)

Customer Energy Management System	Provides automated energy and flexibility management. Based on the CEMS Package of the IDOP.	Baseline and flexibility potential offers Load measurement Control (schedule)
Data Spaces for Buildings and Industrial Sites	IDOP based Data Spaces for sharing data about buildings and industrial sites. The data spaces provide an alternative way (in addition to direct access) for sharing data between the external systems, AEMS and CEMS.	Basically, any data that can be shared between the stakeholders, including: energy consumption and production data, metering point configuration data, building automation data, distribution management data, CO2 emission data, etc.
DevSecOps Tool	Tools for managing CEMS and AEMS services with focus on integration of security as a core part of the development and operations.	AEMS and CEMS deployment commands, system health status, system configuration, software version, etc.
Weather forecast service	A service that provides weather data	Weather data (current, history)
Trust management services	A service that enables establishing trust among entities in the system. Enables recognition of end user identities, their credentials, corresponding resources and their relation to roles in the system.	Trust management data
Distribution management system	Provides the dynamic network tariffs.	Dynamic network tariffs
District heating price service	Provides the current district heating prices	Dynamic district heating prices
CO2 emission service	Provides data about the equivalent CO2 emissions	Energy mix / estimate of the CO2 emission
HEMS	Home Energy Management System that monitors energy flows of the building. Provides information about energy consumption and production, and the state of the flexible assets. Controls the building's energy resources (devices, flexible asset) according to control commands.	Sensor measurement data Resource state Frequency measurements Energy consumption Energy production Constraints for flexible asset Resource control
BAS	Building Automation System that monitors and manages various systems in a building. Provides information about energy consumption and production, and the state of the flexible assets. Controls the building's energy resources (devices, flexible asset) according to control commands	Sensor measurement data Resource state Frequency measurements Energy consumption Energy production Constraints for flexible asset Resource control
Heat pump service	A service that controls heat pump unit(s) and provides energy when required.	Energy consumption Energy production Resource state
Smart meter	An official power meter (i.e., metering point) that enables to remotely read the power and energy measurements.	Power and energy measurement for electricity.
EV charging	A charging station for electronic vehicle. Provides data about energy consumption and production data, and the state, and receives control commands.	Energy consumption Energy production Resource state
PV system	Photovoltaics system, provides data about the energy production and state of the resource.	Energy production Resource state

Awaiting approval

Battery system	A system that stores energy and provides it when needed.	Energy production Resource state
Wholesale market operator	Operates in energy markets	N/A
TSO	Transmission System Operator, operates in reserve and balancing power markets and in local flexibility markets	N/A
DSO	Distribution System Operator, operates in local flexibility markets	N/A
VPP operator / aggregator	A stakeholder who operates / aggregates a virtual power plant.	Goals Preferences Configurations (metering points, markets)
Facility manager	A stakeholder that is in charge of a larger property. Provides goals and preferences, and system configurations, and receives performance reports, system health status, data about energy consumption and production, and energy costs and CO2 emissions	Goals Preferences Configurations (static tariff data, location, PV orientation, storage size) Feedback and manual override (thermal comfort)
Consumer / prosumer	An individual resident. Provides goals and preferences, and feedback on the system operation, and receives energy costs, and energy consumption and production data. As a prosumer, provides tariff data.	Goals Preferences Configurations (static tariff data, location, PV orientation, storage size) Feedback and manual override (thermal comfort)
AEMS / CEMS Provider	A technology provider for the AEMS and/or CEMS platforms. This company is responsible for deployment and operations of the technical systems. Typically, there is a separate companies at for the CEMS and AEMS.	Deployment and operations data System health status (e.g. software version, etc.)

4.2.2 Functional View

In the functional view, the IDOP based system is divided into functional components. Figure 4 describes the functional view of an example system.

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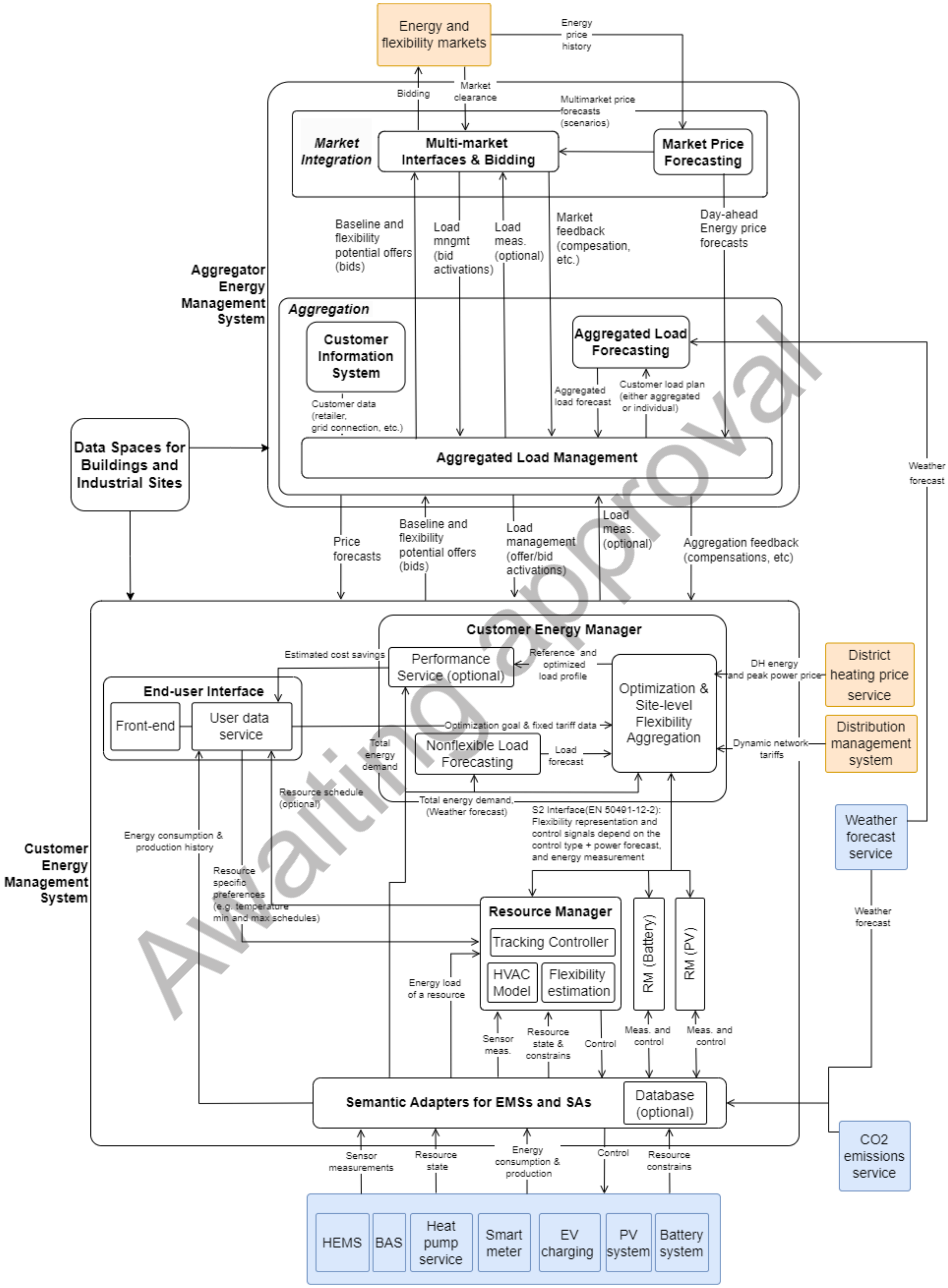

Figure 4: Functional view of the IDOP based system architecture.

Table 16 provides a detailed description of the five functional components of the AEMS. The AEMS components are divided thematically into two groups: Market Integration and Aggregation. This is to highlight that some AEMS can focus just on aggregation without direct interfaces with the markets and can just include the functional components of the Aggregation group (i.e., these AEMS are called sub-aggregation platforms). The interface between the Aggregation and Market Integration parts will be based on the same IEC 62746-4 standard (IEC, 2024) as the CEMS-AEMS interface.

Table 16: Functional components of Aggregator Energy Management System.

	Functional component	Description
Market integration	**Multi-market interfaces and Bidding**	The functional component is responsible for providing mechanism for maximizing the value of flexibility in multi-market operation. To this end, the functional component provides interfaces to energy and flexibility markets including TSO reserve and DSO local flexibility markets. Additionally, the component provides means to optimize aggregated flexibility bids/offers in multi-market setting using the probabilistic market price forecast provided by the Market Price Forecasting component.
	Market Price Forecasting	This functional component is responsible for providing probabilistic price forecasts for a wide variety of energy and flexibility markets.
Aggregation	**Customer Information System**	This component is responsible for providing access the customer related data and metadata required in the aggregation, including e.g. the retailer, metering point id and location in the network topology.
	Aggregated Load Forecasting	The purpose of this component is to provide aggregated baseline and flexibility forecasts. This is an optional component, and the idea is to improve the accuracy of the baseline and flexibility forecast which are initially constructed by the Aggregated Load Management component by adding together the CEMS-level forecasts.
	Aggregated Load Management	This component provides flexibility aggregation (and disaggregation) functionality. I.e., it is responsible for aggregating together the individual baseline and flexibility forecasts from CEMS and disaggregating the accepted flexibility bid for individual CEMS.

Table 17 describes the functional components of CEMS. The CEMS consist of four main functional components which are divided further into subcomponents as described in the Table 17.

Table 17: Functional component of Customer Energy Management System.

Functional component	Description
End-user Interface - Front-end - User data service	The End-user Interface component is responsible for enabling consumers/prosumers (and their representatives) to interact with their CEM. The component consists of two subcomponents: Front-end and User data service.
Customer Energy Manager - Optimization & site-level flexibility aggregation - Nonflexible load forecasting - Performance service (optional)	The Customer Energy Manager component is the core of the CEMS as described in the EN 50491-12 standard (CEN-CENELEC, 2022). Its main function is to optimize energy and flexibility management within the site. The CEM consist of three subcomponents. First, the Optimization & site-level flexibility aggregation subcomponent is responsible for 1) optimizing energy management and 2) aggregating the flexibility provided by the Resource Managers at the site level. For optimization, the subcomponent will utilize Resource data provided via the S2 interface, inflexible load forecasts, and energy price and power tariff data. Second, the Nonflexible load forecasting subcomponent is responsible for providing the baseline forecast for the consumption that is not included to the individual resources. Third, the Performance Service is responsible for storing and providing access to the flexibility management performance data. This is an optional component that will include e.g. data about the estimated savings that have been obtained via flexibility management.

Awaiting approval

Resource Manager - Tracking Controller - Resource Model - Flexibility Estimation	The Resource Manager component is responsible for managing a single resource (device or logical group of devices) within the consumer premises. The main function of the RM is to control the flexible asset according to consumer preferences and expose the flexibility of the asset for the CEM as defined in the EN 50491-12 standard (CEN-CENELEC, 2022). The RM consist of three main subcomponents: Tracking Controller, Resource Model, and Flexibility Estimation. The Tracking Controller is responsible for following the control signals sent by the CEM while making sure that the consumer preferences are satisfied. To this end, it typically utilizes the Resource Model to perform Model Predictive Control (MPC). The Resource Model is also used by the Flexibility Estimation subcomponent that is responsible for representing the flexibility of the asset as defined in the S2 interface.
Semantic Adapters	The Semantic Adapters component provides a common interface for interfacing with building and home automation systems, metering infrastructure, weather forecast service, and other external systems providing information about resources. The idea is that there is a Semantic Adapter for each type of asset/protocol that maps the assets specific interface to a common SAREF aligned representation.

4.2.3 Information view

Table 18 describes the data elements that were identified in the context view and the functional view. The more detailed description of the data items will be provided in phase two of the architecture design and will be described in D2.3.

Table 18: The data elements of the IDOP based system architecture.

Units	Data types	Resources	Systems	Information/ knowledge
•Power, energy, capacity •Temperature, humidity, CO_2	•Measurement data •Price data •Weather data •Report •State data •Constraint •Control data •Feedback data •CO2 estimates	•Sensors •Energy metering •Storages •Batteries	• Distribution management system •District heating management system •Energy management systems (BAS, HEMS) •Third party services (e.g., weather service, CO_2 emission service)	•Laws, standards •Identities •Bidding description

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4.2.4 Deployment View

Deployment view represents how the components of a system are implemented by software artifacts and how these software artifacts are deployed into different computing platforms. Figure 5 illustrates how the example IDOP based DSFM system is deployed.

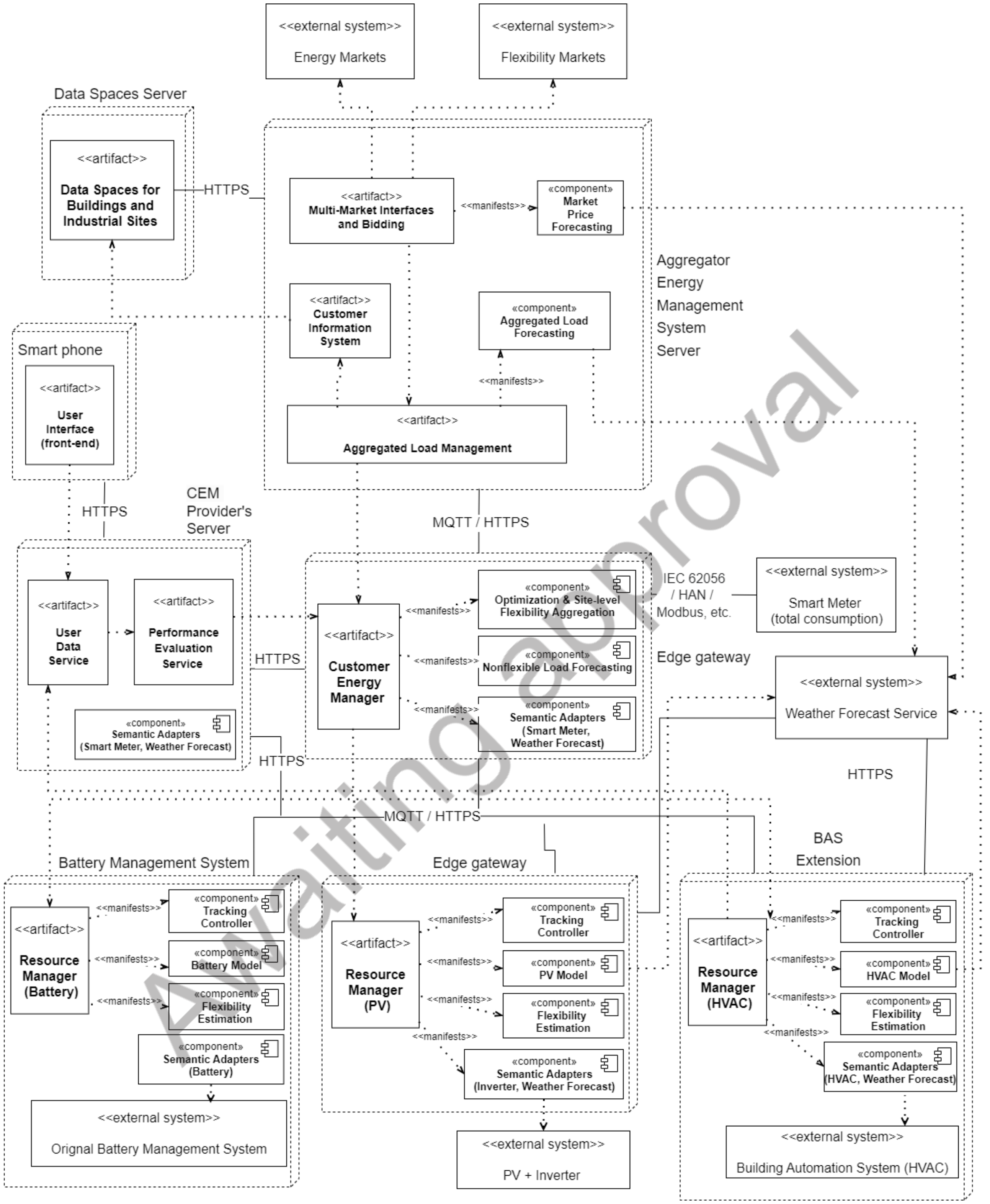

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Figure 5: Deployment view of an IDOP based system.

The deployment example consists of a single CEMS (in practice there would be thousands) and AEMS. The CEMS consist of a Customer Energy Manager and three Resource Managers.

Starting from the bottom left, there is a RM integrated to a Battery Management System (BMS). In this example, the BMS system provider has extended their BMS system with standard-compliant RM. The RM consist of following subcomponents: Tracking Controller, Battery Model, Flexibility Estimation and Semantic Adapters for the BMS. The RM for the PVs in the middle in turn is implemented by a 3rd party on an edge gateway. The third RM is implemented by the building automation system provider, and it is deployed in the same computing platform as the BAS.

The CEM in this example is deployed on an edge computing platform hosted in the consumer premises. It consists of following sub-components: Optimization & Site-level Flexibility Aggregation, Nonflexible load forecasting, and Semantic Adapters for smart meter and weather forecast integration. The deployment of the End-user interface component of CEMS is distributed. The front-end part is deployed in a smart phone whereas the User Data Service (i.e., back-end part) is deployed in a server. In this example the same server hosts the Performance Evaluation Service.

In this case there is a single aggregator providing aggregation and market integration services. The whole AEMS is therefore deployed into single server hosted by the AEMS provider. The deployment includes also Data Spaces that are deployed into as separate services.

Although not explicitly depicted in Figure 5 for clarity reasons, The DevSecOps module plays an important part in the deployment and operations of IDOP-based DSFM systems. The DevSecOps module will provide tools and services that can be used in every stage from development to production deployment. It will utilize the “shift-left” philosophy, aimed at discovering potential vulnerabilities, bugs and misconfigurations as soon as possible. To achieve this, it will combine dependency testing, image scanning, infrastructure scanning and compliance checking as an addition in the classic DevOps pipeline. This, in combination with tools for secure secret management, will provide secure deployment capabilities to the project. The module will also have a monitoring stack with alerting, as well as the means to securely deploy multiple cluster environments with all the required services.

4.2.5 Trust, security and privacy perspective

Trust, security, and privacy are of great importance for the proposed platform. Trust denotes a need in a system for stakeholders, actors, and entities to build relationships with each other, aiming to enable access to each other's data and resources. While doing so, access needs to be controlled and allowed only if all parties agree on the intended actions in the system. Security elements of the system are responsible for implementing access control in a way suitable for the system's scale and performance. The security elements also provide basic mechanisms for privacy provisioning in accordance with EU privacy regulations.

In a difference to the DevSecOps module as described in Sections 4.1 and 4.2.4 the trust, security and privacy (TS&P) provides a set of basic security services needed in the IDOP system. Entities in the system need to be properly authenticated, authorizations of the entities clearly defined and resulting policies decisively enforced. Communication between the entities needs to provide data integrity, authentication and confidentiality services. Non-repudiation of actions taken in the system should be provided. The DevSecOps module provides supporting services for secure deployment of the services and their operation but does not provide the basic security and privacy services for the end user. The cooperation between both sets of services is needed to deploy the TSP services securely. The DevSecOps can play a crucial role in trust and security bootstrap and provide means to distribute needed system entities credentials and basic policies in the IDOP system.

According to the functional view of the IDOP based system architecture, see Figure 4, the interface between the Aggregator and Customer Energy Manager (CEM) is the major interface in the system. The interface is planned to be compliant with the IEC 62756-4 standard (IEC, 2024). Besides the major interface there are important two additional interfaces: The interfaces between CEM and Resource Managers (RM) and between End User Interface and CEM and RMs. The interface between the CEM and RM follows recent EN 50491-12-2:2022 standard (CENELEC, 2022). No specific standards have been considered for interfaces between the EUI and the CEM and RMs.

Neither IEC 62756-4 or EN 50491-12-2:2022 does not specify any explicit TS&P requirements or normative references the standards should comply to. The IEC standard is part of a broader family of IEC 62756 standards that includes standards on use cases IEC TR 62746-2:2015 and IEC TS 62746-3:2015 on architecture (IEC, 2015). The architecture document lists some of the security requirements that are important for the implementation of the IEC 62756-4 standards as well:

- to avoid inbound connections and related security problems the architecture introduces a communication server the clients (VEN - Virtual End Node in the IEC 62756-4 nomenclature) connect through to the aggregator (VTN - Virtual Top Node),
- role based access control should be provided to manage privileges to access and manage the resources,

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- the communication between the clients and the server should be secured, mutual authentication should be supported and non-repudiation should be provided,
- the communication server is a trusted entity for both clients and the server. Security services provisioning should take into account implications of key management for selected transport specific mapping (e.g. TLS, MQTT, etc.),
- the security burden on the client and server should be minimal though both, the client and the server need to provide security measures aligned with the devices with online Internet connection.

The EN 50491-12-2:2022 standard provides no information on how to handle TS&P issues related to the standard implementation. If the RMs are not integral part of the CEM process or if the entities communicate through open communication channels, like communication server mentioned beforehand, TS&P services need to be provisioned for the CEM and related RMs. The relationship between the entities, the CEM and RMs, needs to be established and managed properly.

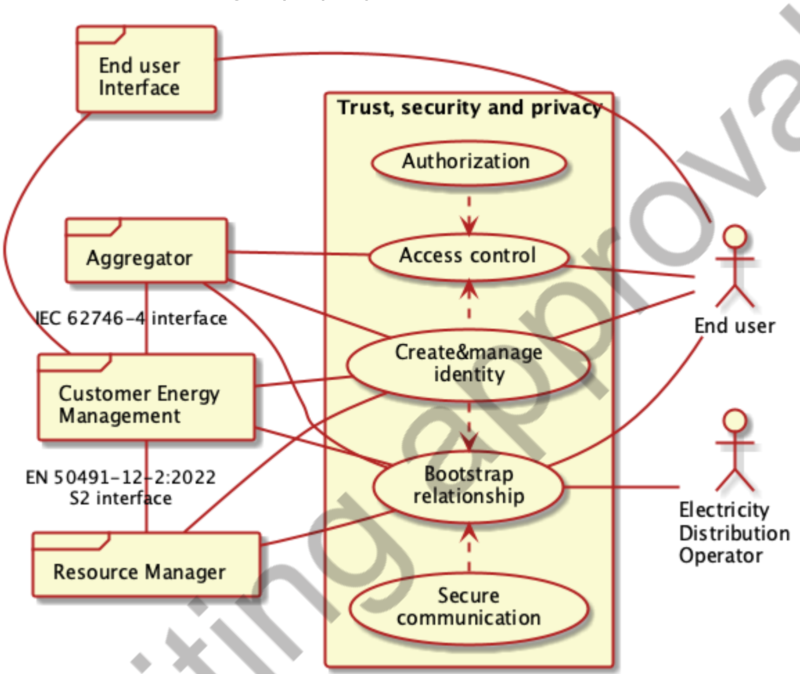

Figure 6: Trust, security and privacy system use case diagram

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The Figure 6 present TS&P a system use case diagram. There are 2 actors and 4 system entities denoted in the diagram. The actors are the end user, either a household owner, an industrial plant owner, a building manager, etc. and the Electricity Distribution Operator (EDO). The system entities are the Aggregator, the Customer Energy Manager, the Resource Manager and the End User Interface. The actor EDO is added to the use case diagram for two, trust establishing reasons. First, the EDO can vouch that somebody has a control over the end user network. For example, the EDO can issue a Digital ownership certificate for the smart meter owner, so everybody can validate if the identity stated in the certificate can manage the network behind the meter referred in the same certificate. Second, the EDO, or any other suitable entity under each particular country's legislation, can vouch by issuing a digital statement that some entity can perform aggregator operations in a particular electrical network or its part. These two digital statements can be used to boost up the use cases foreseen in the use case diagram.

The following TS&P use cases are foreseen for the IDOP system:

1) *Create and manage identities*: this is a central use case, needed for realization of all the other use cases. Each system entity and actor need its own identity to be able to start building relationship with other entities and actors. There is a number of possibilities how to manage identities. A hierarchical approach like X.509 based identity management is suitable for both small and large deployments. Nowadays, an approach oriented towards the end user like Self Sovereign Identities (SSI) seems to be more practical and user friendly. Whichever approach is chosen each entity and actor should have one or more identities available that can be used in the following use cases;

2) *Bootstrap relationship*: there are a number of relationships that need to be established in a working IDOP system. From already mentioned relationship between the EDO, aggregator and the end user, aggregator and CEMs, CEM and related RMs and End User Interface (EUI) and CEM. Some are purely technical relationships and some will involve also the actors. The relationships can be boosted up with a proper distribution of digital statements and certificates as a kind of trust policies between the system entities. The DevSecOps framework can help to build proper and secure distribution of trust anchors so the system can start connecting securely and restrictively right away. Such solutions can be suitable for example for CEM and RMs bootstrap while for aggregator and CEM/end-user connection a simple web-based application can be helpful;
3) *Secure communication*: the identities are a cornerstone for secure communication. They are used to establish a secure, mutually authenticated communication channel. The TLS protocol in the case of X.509 framework or the DIDCOMM in case of SSI are examples of such secure communication channels. The entities can use the channels to exchange information, reach agreements, etc. When used over the communication server like MQTT a trust needs to be placed in the server to transmit the traffic between the entities securely and privately. The point-to-point connections terminate at the server and the information is at the server decrypted and encrypted again;
4) *Authorization*: the authorization is an approval that is granted to system entity to access a system resource. It also denotes a process of granting the approval. The mechanisms for implementing the authorizations are needed. Authorizations can be granted to identities through the system and resources naming design, by implementing role-based access control and by implementing delegation for access through authorization credentials. These mechanisms enable implementation of fine-grained access control. The authorizations should be designed to allow implementation of the principle of least privilege which implies that each system entity is granted the minimum system resources and authorizations that the entity needs to do its work;
5) *Access control*: access control provides both availability for authorized entities as well the confidentiality service. Only entities allowed to access a certain piece of information are able to read or modify it. A simple implementation of role-based access control is when the identities are roles. In this case the identities are used to access the resources and govern who can change the set-point on HVAC or read the detailed smart meter measurements. The policies can be embedded in the naming of resources, e.g. identities can be parts of topics for communication (MQTT case) or URLs in the case of the REST API. If the access control involves more complex information, contained in the authorization credentials and obtained from the resource call environment, the access control process needs to obtain all the information and validate its integrity before using the information in the process of obtaining access control decision. The access control needs to provide an enforcement layer where the authorization and system policies are properly enforced.

Awaiting approval

4.2.5.1 Trust, security and privacy requirements

Based on the discussion, the trust, security, and privacy requirements for the INDEPENDENT Platform can be outlined as are set in the flowing Trust requirements, Security Requirements and Privacy requirements tables.

Table 19: Trust Requirements

ID	Requirement	Description
TR1	Manage identities	Manage identities of the system entities in a privacy preserving manner and in a scalable way fit for intended IDOP usage
TR2	Manage trust between system entities	Bootstrap the relationships between system entities and actors in a secure and privacy preserving manner

Table 20: Security Requirements

ID	Requirement	Description
SR1	Secure communication	Ensure secure communication channels between different entities in the system, utilizing standardized security protocols
SR2	Access control sensitive assets and data	Implement access control mechanisms in a way suitable for the system's scale and performance. Guard access to sensitive assets and data through authorization policies and their enforcement at system interfaces

Table 21: Privacy Requirements

ID	Requirement	Description
PR1	Compliance	Ensure compliance with EU privacy regulations
PR2	Explicit data flows	Establish explicit data flows to provide information about data origins, rightful owners, data nature, and data consumers
PR3	Explicit consent	Require end-user explicit consent for data processing and ensure the presence of the intended data processor among authorized processors
PR4	Data minimization	Implement data minimization techniques to collect and process only the necessary data
PR5	Transparency	Provide transparency for end-users about data collection, processing, and sharing pr
PR6	By design	Develop novel mechanisms through privacy-by-design and privacy-by-default principles, ensuring privacy considerations are integrated into the system from its inception

In a combination with the DevSecOps work as described in Sections 4.1 and 4.2.4 the trust, security and privacy requirements can provide a high level of security and privacy in future instantiations of the INDEPENDENT platform.

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5 System use cases

This section describes three system use cases that enable to design the interactions of the IDOP based system components in more detail.

5.1 Demand-side flexibility aggregation for energy wholesale markets

This system use case focuses on exploiting the demand-flexibility provided by the CEMS in the energy wholesale markets. Figure 7 illustrates an example interaction between functional components in the given system use case. The example scenario starts with a price forecast for the day-ahead market provided by the Market Price Forecasting component. The Aggregated Load Management component forwards this message to the Customer Energy Management Systems connected to the Aggregator Energy Management System. The example scenario is simplified so that only two CEMS are depicted. Each CEMS will use the price forecast to optimize their energy consumption. In addition to the price forecast, various factors such as user preferences, power tariffs and coefficient of performance can influence the local optimization performed by CEMS. Please refer to section 5.3 for a detailed description of the local optimization SUC. In addition to the local optimization that produces a baseline load profile, the CEMS also estimates the flexibility and required compensations (i.e., possible deviation from the baseline at different time periods and the costs caused by this). Each CEMS then sends the baseline and flexibility potential offers to the AEMS.

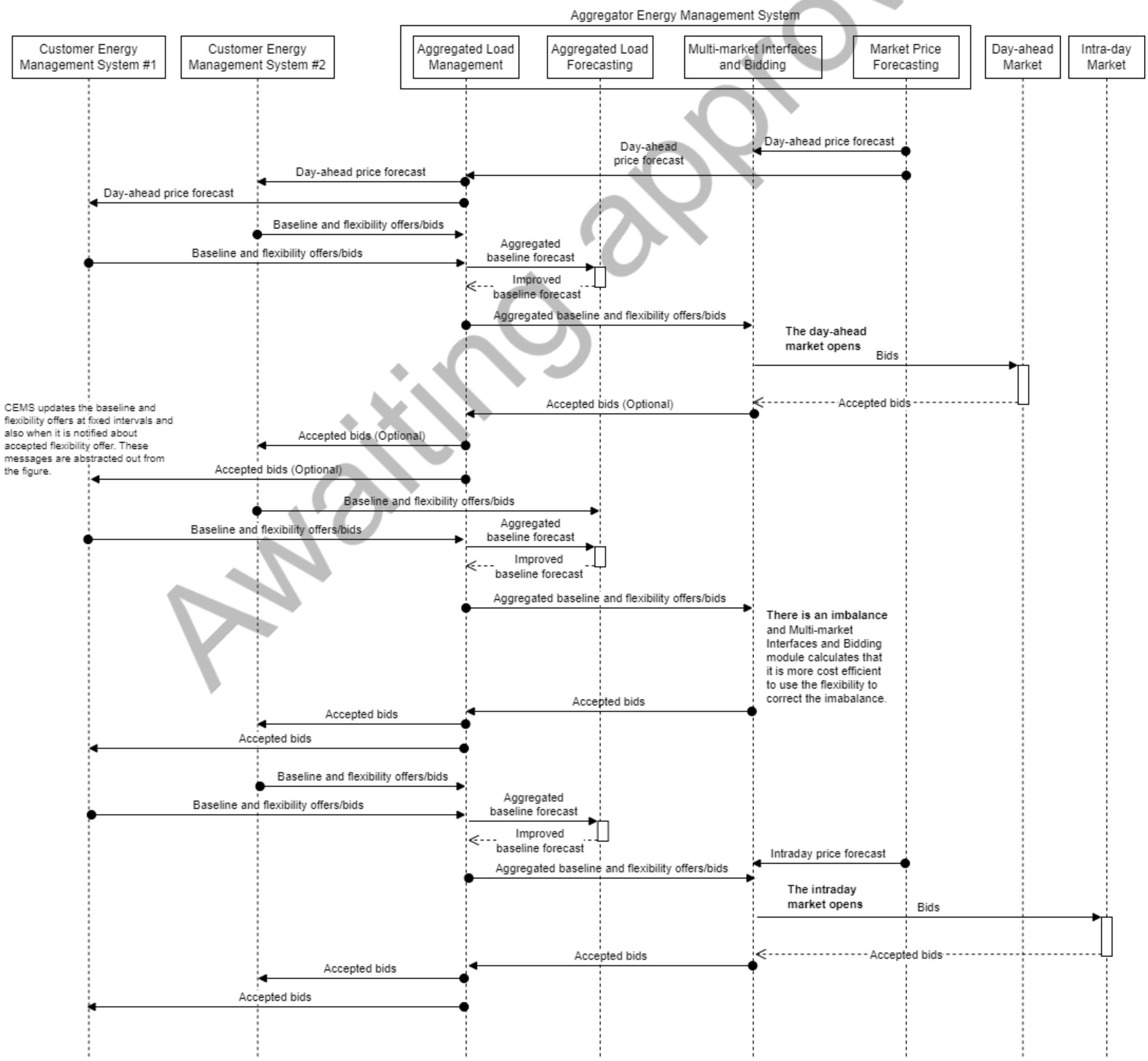

Figure 7: Sequence diagram of demand-side flexibility aggregation for energy wholesale markets.

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Inside the AEMS, the Aggregated Load Management component aggregates the individual baselines. Then it passes the aggregated baseline load profile to the Aggregated Load Forecasting component to improve the accuracy of the forecast. The aggregated baseline and flexibility offers are sent to the Multi-Market Interfaces and Bidding module, which procures energy from the day-ahead market based on the aggregated baseline load profile. It should be noted that the scenario describes in this SUC is simplified as we do not perform proper multi-market optimization (if this would be the case the flexibility and price forecast for different markets would need to be considered in the optimization). Once the day-ahead market is cleared, the AEMS will be notified about the accepted bids. In this simplified scenario the price needs to be set so that all bids will be accepted. Therefore, it is not necessary to notify the CEMS about the accepted bids (i.e., CEMS can assume that they can follow the locally optimized baseline).

There are always some errors in the baseline load forecasts, which means that the energy acquired from the day-ahead market does not match with the actual consumption. This causes some costs to the aggregator (and eventually to the consumer). To this end, the CEMS will update their baseline (and flexibility offers) at fixed intervals (and when notified about accepted bids). Again, this data is first aggregated and then sent to the Multi-market Interfaces and Bidding module. Forecasts typically become more accurate as the time of energy usage approaches. Leveraging this improved accuracy, the aggregator estimates potential imbalances throughout the day and utilizes flexibility to correct them when it reduces overall costs—specifically, if flexibility offers from CEMS are cheaper than imbalance costs. In this case the Multi-market Interfaces and Bidding module accepts the bids from the Aggregated Load Management module to shift energy demand so that imbalances are reduced. The Aggregated Load Management component then disaggregates the flexibility bid (based on the latest CEMS-level flexibility offers) and informs the CEMS about the accepted flexibility offers. After received notification about an accepted bid each CEMS will reoptimize the baseline and flexibility while making sure that the flexibility offered can be provided. The AEMS is then notified about the updated baseline and flexibility offers. There can be several iterations where the AEMS accepts flexibility offers and informs the CEMS about them if required to reach more optimal balance.

The final phase of the SUC focuses on using the flexibility to reduce costs by trading in the intra-day market. Similarly to the day-ahead market phase, this phase is initiated with the intra-day market price forecast. This time the information is only used by the Multi-market Interfaces and Bidding component to make bids and offers to the intra-day market. In addition to the market price forecast, the Multi-market Interface and Bidding component will utilize the latest flexibility offer data from the Aggregated Load Management component in the bidding process. After the Multi-market Interface and Bidding module has received a notification of the accepted bids and offers, it will notify the Aggregated Load Management module about the bids and offers. Similarly to the other scenarios, the Aggregated Load Management module will disaggregate the accepted bids and send individual accepted bid notification for each CEMS.

5.2 Demand-side flexibility aggregation for TSO reserve markets

This system use case, illustrated in Figure 8 below, focuses on aggregating demand-flexibility from CEMS for participation in TSO reserve markets (FCR-D, FCR-N, aFRR, mFRR). After the pre-study where the asset (e.g., heat pumps, batteries, or combinations) demonstrates capability for the specific reserve product we move to the pre-qualification, where the asset must demonstrate their technical capability to meet specific reserve product requirements like response time, duration, and accuracy. The AEMS maintains a registry of pre-qualified resources and their verified capabilities through the Customer Information System, establishing the maximum volume that can be bid into each reserve market.

The operational interaction between functional components starts with parallel forecasting streams:

- The Market Price Forecasting component provides price forecasts for the reserve products, considering historical clearing prices and market conditions.
- Within each CEMS:
    - The Resource Manager's Neural ODE models assess the asset's current state and dynamic response capabilities.
    - The Resource Manager predicts baseline consumption and available symmetric/asymmetric flexibility.
    - The Customer Energy Manager determines reserve capacity offers while ensuring operational constraints and user comfort requirements are maintained.

Each CEMS then sends its baseline and reserve capacity offers to the AEMS. The Aggregated Load Management component combines these individual offers with the validated customer data from the Customer

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Information System, ensuring that only prequalified resources are included in the aggregated portfolio. This combined data is used by the Aggregated Load Forecasting component to produce aggregated capacity forecasts at the portfolio level. The Multi-Market Interfaces & Bidding module uses these forecasts along with market price data to formulate reserve capacity bids that meet TSO product requirements.

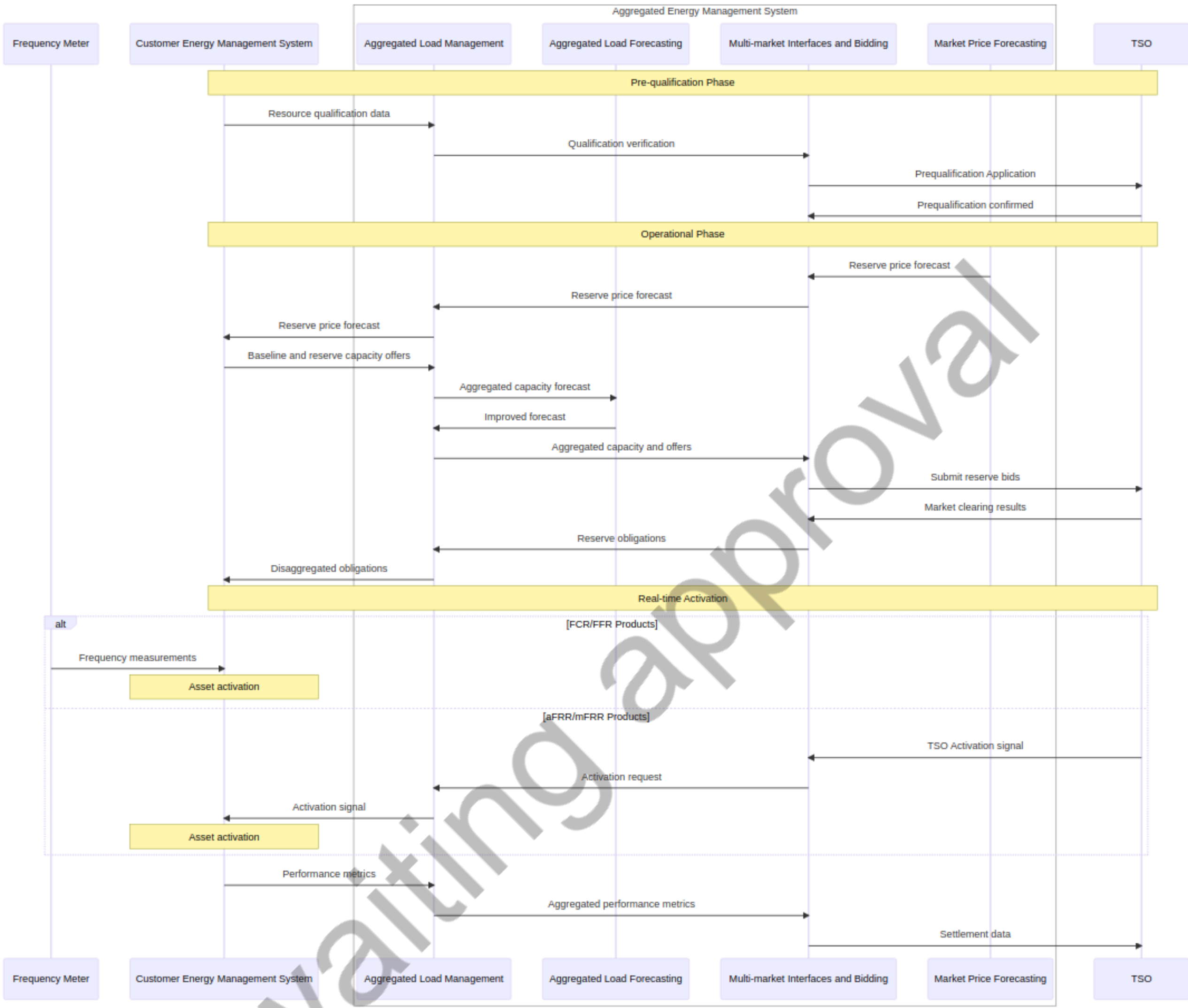

Figure 8: Sequence diagram of demand-side flexibility aggregation for TSO reserve markets.

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When market clearing results are received, the reserve obligations flow through the Aggregated Load Management component to individual CEMS.

Delivery Period Management:

1. The Performance Service tracks activation performance based on:
    a. Frequency response (FCR, FFR) or,
    b. Activation signals (aFRR, mFRR) against TSO requirements.
2. Resource Managers monitor asset state and readiness for activation.
3. Updated reserve capacity and availability status flow through the system.
4. Aggregated Load Management maintains real-time view of available reserve capacity.
5. Multi-Market Interfaces & Bidding handles capacity adjustments if needed.

For real-time activation:

1. The Multi-Market Interfaces & Bidding component receives:
    a. Frequency deviation signals (FCR, FFR) from local frequency meters or,
    b. Activation signals from the TSO (aFRR, mFRR).
2. Activation signals flow through Aggregated Load Management to Customer Energy Managers.

3. Resource Managers execute asset/system response through their controllers.
4. The Performance Service component monitors response time and accuracy.
5. Settlement data flows through the system for verification and compensation based on reserve product performance metrics.

5.3 Local flexibility management

The local flexibility management system use case covers how individual end users manage their flexibility with the resources at their disposal. The end users can be households, apartment buildings, industrial plants and facilities, public buildings, retail establishments, etc. The SUC assumes that the end user resources are managed through a Customer Energy Management (CEM) system and each particular end user case can have multiple Resource Managers (RM) at their disposal, like HVAC RM, PV RM, Battery RM, etc. End users manage their resources to leverage flexibility for various goals, such as reducing costs, energy usage, CO2 emissions, and improving resource efficiency.

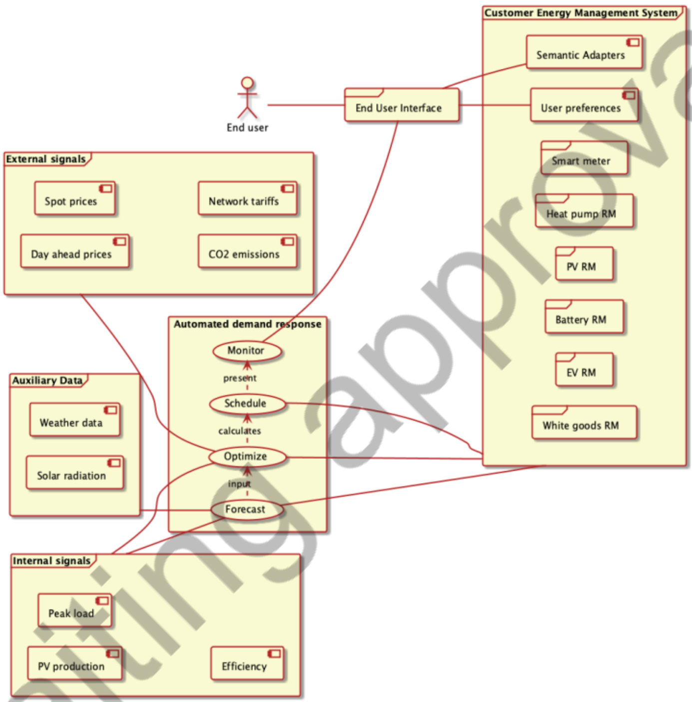

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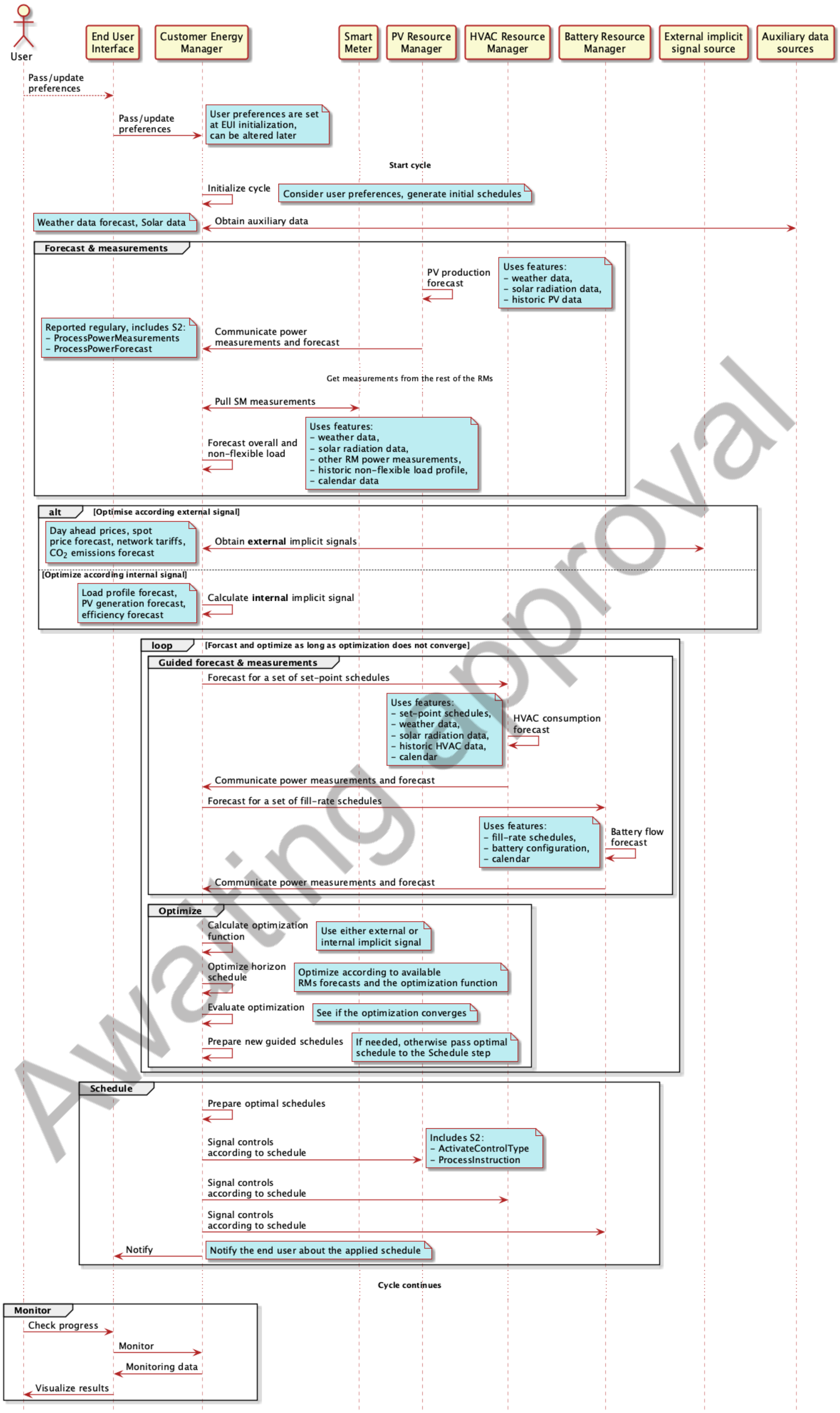
Figure 9: Local flexibility use case diagram

The use case diagram in Figure 9 presents essential elements of the use case and basic steps performed during use case execution. The end user accesses information about the system through the End-user Interface (EUI). The EUI is used to set the end user preferences and to monitor the system performance. The CEM encapsulates the RMs available at the end user premises and the smart meter (SM). Semantic adapters are used to enable unified access of the RMs to the Resources and for coherent EUI access to the monitoring data. The execution of the use case is guided by external or internal signals. The external signals can be, for example, day ahead prices, spot prices, CO2 emissions or network tariffs. As the internal signals a PV production at the premises, load profile with its peak load, or an efficiency of certain resources. Auxiliary data such as weather or solar irradiation is needed for the use case implementation.

Awaiting approval



Awaiting approval

Figure 10: Local flexibility management use case sequence diagram

The basic steps of the use case are forecast, optimize, schedule and monitor. In the forecast step the internal signals employed in the use case are forecasted for foreseen time horizon. Most of the external signals, if employed, also need a forecast for the time horizon. We assume that external services are available that can provide suitable predictions for the use case needs. Similar assumption is held for the auxiliary data. The forecasts for the individual RMs consumption in the horizon is provided by the RMs themselves. The forecast for the non-flexible loads is provided by the CEM based on smart meter measurements.

In the optimization step, based on end user goal, a selected signal is transformed into an optimization function. The optimization process, based on the function and individual RMs forecast calculates an optimal schedule for the RMs in the next time horizon. In the next step a schedule is prepared and communicated by the CEM to the RMs. The end user in notified about the schedule and can monitor its execution through the end user interface.

The details of the use case are presented in the use case sequence diagram in Figure 10. The diagram is split in three parts. In the first part the end user uses EUI to set its preferences regarding the system managed. The preferences are initialized at the EUI initialization and can be altered later. The preferences define the specific goal(s) of the end user as well operating conditions and limitations of the CEM and related RMs. In the second part is an operation cycle which can be triggered every hour or every 15 minutes. In the cycle the CEM calculates the optimal schedule for the next time horizon. The time horizon depends on horizon settings and available forecast needed for calculation. A typical time horizon is a day. The third part is monitoring of the progress of the operation of the system that is available for the end user at any time.

The management cycle begins with initialization, where the current user preferences are taken into account. Initial set of schedules for the controllable RMs are prepared. The schedules should adequately cover the controllable space of the RMs and the time horizon for initial optimization. The weather and solar irradiation data are obtained from auxiliary data sources.

The forecast and measurement part covers obtaining the measurements and next time horizon load and generation forecast from all the RMs the CEM controls. As an example, a Photo Voltaic (PV) RM case is presented in the diagram. The rest of the RMs follow the same pattern. The load and generation forecast are calculated by the particular RM. The communication of the RMs follows the S2 standard (CENELEC, 2022), the measurements and the forecasts are sent regularly to the CEM. The CEM calculates overall and non-flexible loads forecast based on the measurements pulled from the smart meter and the measurements sent by the RMs.

In the next step either external signal is obtained or internal signal calculated. The external signal forecasts are obtained from External implicit signal sources. In the case of day ahead prices, forecasted spot prices or network tariffs the system would aspire to minimize cost of energy consumed. The flexible loads consumption should be shifted to the periods when the costs are lower. The internal implicit signals are calculated from the forecasted smart meter or PV RM data. In the case of the smart meter forecast the system would, for example, shift the flexible loads consumption with an aim to lower the overall peak of the consumption. When the PV generation is used as the implicit signal the flexible loads should be shifted towards the times of high generation to optimize for self-consumption.

The next two steps, the controllable RMs forecast and optimization are performed in a loop. The loop continues until the evaluation of the optimization results is positive. The loop can be time limited. If the results of the evaluation are not satisfactory, the default schedule is used as a fallback for the cycle.

For the set of controllable RMs the schedules, prepared in the initialization step of the cycle, are used to get forecasts from each individual RM. In the diagram examples of features used for preparing the forecast are listed. The RMs return a set of load profiles forecasts associated with each input schedule together with the past measurements.

In the optimization step, an optimization function is created based on the user's goal(s) and the implicit signal. The optimization process uses the forecasted RM load profiles along with the optimization function to determine the optimal schedules for the RMs. The optimization is evaluated. If positive, the schedules are passed to the scheduling step otherwise new set of guided schedules are prepared for the next Guided forecast and optimization loop.

Based on the optimized schedules the CEM prepares the schedules for the RMs. The schedules are communicated to the RMs according to the S2 standard (CENELEC, 2022). The end user is notified through the EUI about the applied schedules.

Awaiting approval

6 Conclusion

This document describes the work done in three WP2 tasks: use cases and requirements engineering, common architecture of the IDOP based system, and trust, security, and privacy design for the IDOP based architecture.

The document provides the following:

- Business use cases and requirements engineering: The use cases emerge from large-scale pilots of four countries and are described from the business viewpoint. The use case analysis ends up with an initial set of common requirements associated to CEMS, AEMS, and DevSecOps & Investment Support Packages.
- Common architecture of the IDOP based system: The architecture of the IDOP consists of three main packages: CEMS, AEMS, and DevSecOps & Investment Support Package. The architecture design is an iterative process, following the relevant standards, such as ISO/IEC/IEEE 42010:2011 standard. The architecture of an IDOP based system is described from the context, functional, information and deployment viewpoints. The architecture is refined further with four system use cases that enable to identify more detailed functionalities for the components.
- Trust, security and privacy design: The TS&P are addressed holistically from the start. Multiple TS&P dimensions are explored from the use cases, including trust and identity management, secure communication between components and entities, secure and privacy aware data spaces provisioning, and implementation and operations oriented DevSecOps. The trust, security, and privacy requirements for the INDEPENDENT Platform are outlined as a result.

Awaiting approval

7 List of figures and tables

7.1 Figures

7.2 Tables

Awaiting approval

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